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FERTILIZER STUDIES WITH SUGAR BEETS IN THE ARKANSAS VALLEY AREA, COLO., 1921–28

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INTRODUCTION

This circular gives the results of tests with commercial fertilizers on sugar beets grown on different types of soil in the Arkansas Valley area in Colorado. The soils of that area vary as to origin and productivity. In the eastern part of the valley the soils are predominantly heavy in texture, being mostly silt loams and silty clay loams, while those west of Rocky Ford, Colo., are somewhat lighter in texture and are composed largely of medium to fine sandy loam types. For a detailed discussion of the soil types the reader is referred to a recent soil survey [1] which deals largely with the cultivated areas of this valley. In the 12 soil series mapped in this survey were included 32 major soil types and 16 phases of types.

The Arkansas Valley area is an important agricultural district, in which a large number of staple and special crops are grown under irrigation. In the eastern part of the valley sugar beets, alfalfa, small grains, and corn are the leading crops, a small acreage being devoted to truck crops grown in rotation with the sugar-beet crop. In the western part of the valley there is a greater diversity in cropping practice. There, truck crops, including cantaloups, onions, beans, tomatoes, and other crops grown for market and for seed, form a considerable proportion of the crops in rotation with sugar beets. In that section, grain is generally grown only as a nurse crop for alfalfa, the proportion of which is considerably less per farm than in the eastern part of the valley. The possibility of soil type and cropping practice influencing the quality and yield of beets was early recognized, and records kept by a sugar company operating in the valley in general show that higher quality beets but somewhat smaller tonnages are produced on the lighter textured soils. Because of need for sufficient beet tonnage with which to operate the beet-sugar factories to capacity, no attempt has been made to restrict the growing of sugar beets to certain soil types.

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[1] Sweet, A. T., and Inman, W. SOIL SURVEY OF THE ARKANSAS VALLEY AREA, COLORADO. U.S.Dept. Agr., Bur. Chem. and Soils, Soil Survey Rpt. 24, Ser. 1926, 46 pp., illus. 1930.

Fertilizer studies with sugar beets had been in progress for more than 10 years prior to those begun in 1921 by the Division of Soil Fertility of the United States Department of Agriculture. As early as 1908 the management of one of the beet-sugar companies operating in this area realized that the yield and quality of the beet crop were unsatisfactory. The leaf-spot disease was recognized as important at that time since it was known that both quality and yield of the crop were adversely affected in years when this disease reached epidemic proportions. In the period from 1909 to 1920, so far as could be judged from the yield of the beet crop in years when production was not decreased by the leaf-spot disease, the productivity of the soil appeared to be declining. Experimental work with commercial fertilizers was undertaken at that time by the research department of one of the beet-sugar companies but gave indecisive results. The failure of these earlier experiments to indicate a definite fertilizer response may undoubtedly be attributed to the fact that the soils of the area had been cropped to sugar beets for only a comparatively short time and therefore the depletion of essential plant-food elements in the soil was only beginning to become a serious problem.

Thus the present work was begun at a time when the beneficial effect of fertilizer applications had not been shown and the fertilizer requirements of the soil were undetermined. The experimental methods followed were based upon those in use by the Division of Soil Fertility in similar investigations with other crops. During the period from 1921 to 1928, inclusive, 31 experiments with commercial fertilizers were made, and the effect of various fertilizer combinations, sources of plant food in the fertilizer mixture, and rates of application were studied.

The work was carried on by means of experimental field tests on plots one-twentieth to one-fourth of an acre in size (depending on the nature of the experiment and the number of fertilizer mixtures used) in which the effects of various fertilizer combinations on the beet crop were compared. Usually every fourth plot was left untreated to serve as a check. Applications were not as a rule replicated, the consistency of check performance and the trend shown by the relative combinations being the criteria used in interpreting the findings. Standard beet-growing practice was followed in these experiments, and all plots received uniform cultural treatment.

The fertilizer was applied with the seed, the required amounts being distributed as uniformly and accurately as possible in the row with a drill. After being planted, the plots were promptly furrow-irrigated to avoid the possibility of injuring the germination stand by letting the seed come in contact with large amounts of fertilizer. At harvest time the entire plot was harvested and yields recorded on the basis of actual yield of tared beets. The size of the plot governed the number of samples taken for analysis, which varied from a minimum of two to a maximum of five 10-beet samples selected at random. On these samples the percentage of sucrose was determined by the Sachs-Le-Docte [2] cold-water digestion method. The gross pounds of sugar per acre were obtained by multiplying the yield by the percentage of sucrose and averaging the individual plot values. Where plots were replicated, such values differ slightly from the product of the means given in the various tables.

EXPERIMENTAL WORK [3]

THE FERTILIZER RATIO

One or more field experiments were undertaken in 1922, 1923, and 1925, in which the triangle method of fertilizer experimentation was employed.[4] This method consists of using the fertilizer constituents, nitrogen, phosphoric acid, and potash, singly or in combinations of 2 or 3, and varying the ratios in 20-percent stages. By the use of the 21 different fertilizer combinations of the triangle (as shown in fig. 1), the effect of the entire range of fertilizer ratios was determined. A 4-percent gradient in plant food between the successive fertilizer combinations was used, and the total amount of plant food applied per acre was held constant for all fertilizer combinations. The combinations used are given in connection with the various tables. From the results of this exploratory work, it was possible to ascertain in which portion of the triangle the response from applications of fertilizers was most pronounced.

Once this had been determined, the selection of the specific mixture or mixtures most likely to yield the best results could be undertaken. In the first experiment (1921), 150 pounds of plant food or 750 pounds of a 20-percent mixture was applied per acre. The largest acre yields of sugar were obtained with the 4–12–4 [5] fertilizer mixture. It became apparent from this preliminary experiment that the amount of plant food used per acre was excessive; however, the experiment served as a guide for future work.

In 1922 three sets of experiments were located at Rocky Ford, Wiley, and Lamar, Colo., on the Rocky Ford fine sandy loam, Prowers clay loam, and Prowers clay loam, poorly drained phase, respectively. The plots used in these experiments were one-twentieth acre each in area, 4 rows wide, and 327 feet long, with rows 20 inches apart. Seventy-five pounds of plant food, or 375 pounds of a 20-percent mixture per acre, were applied in the row (table 1).

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[2] BROWNE, C. A. HANDBOOK OF SUGAR ANALYSES; A PRACTICAL AND DESCRIPTIVE TREATISE FOR USE IN RESEARCH, TECHNICAL AND CONTROL LABORATORIES. pp. 242–244. New York and London. 1912.

[3] Acknowledgment is hereby made to F. R. Reid, of the Division of Soil Fertility, for hearty cooperation in the planting and harvesting of the experimental plots.

[4] SCHREINER, O., and SKINNER, J. J. THE TRIANGLE SYSTEM FOR FERTILIZER EXPERIMENTS. Jour. Amer. Soc. Agron. 10: 225–246, illus. 1918.

[5] Percentages, respectively, of nitrogen, phosphoric acid, and potash.

TABLE 1.—*Results of applying fertilizer to sugar beets at the rate of 75 pounds of plant food per acre at Rocky Ford, Wiley, and Lamar, Colo., 1922*

Treatment no.	Mixtures (N-P_2O_5-K_2O)	Yields of beets per acre				Sucrose				Sugar production per acre			
		Rocky Ford	Wiley	Lamar	Average	Rocky Ford	Wiley	Lamar	Average	Rocky Ford	Wiley	Lamar	Average
		Tons	*Tons*	*Tons*	*Tons*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1	20–0–0	11. 21	11. 41	11. 98	11. 53	16. 7	15. 7	12. 1	14. 8	3, 744	3, 584	2, 897	3, 408
2	16–4–0	15. 13	13. 28	13. 61	14. 01	15. 7	15. 6	13. 6	15. 0	4, 752	4, 143	3, 703	4, 199
3	16–0–4	11. 35	11. 58	12. 03	11. 65	14. 6	14. 4	14. 4	14. 5	3, 313	3, 334	3, 465	3, 371
4	12–8–0	14. 28	13. 10	15. 14	14. 17	14. 5	15. 3	13. 2	14. 3	4, 142	4, 007	3, 997	4, 049
5	12–4–4	16. 01	12. 08	13. 82	13. 97	15. 3	15. 0	12. 1	14. 1	4, 900	3, 625	3, 343	3, 956
6	12–0–8	11. 28	11. 88	11. 41	11. 52	15. 6	13. 8	14. 9	14. 8	3, 519	3, 279	3, 400	3, 399
7	8–12–0	14. 12	13. 65	13. 77	13. 85	14. 6	13. 8	14. 1	14. 2	4, 123	3, 767	3, 884	3, 925
8	8–8–4	13. 66	12. 51	13. 75	13. 31	14. 8	15. 0	13. 2	14. 3	4, 042	3, 753	3, 630	3, 808
9	8–4–8	13. 96	12. 75	14. 16	13. 62	15. 2	14. 6	13. 5	14. 4	4, 245	3, 723	3, 823	3, 930
10	8–0–12	11. 51	12. 94	11. 37	11. 94	16. 4	14. 8	13. 8	15. 0	3, 774	3, 830	3, 138	3, 581
11	4–16–0	13. 69	15. 23	15. 17	14. 70	14. 9	14. 3	14. 3	14. 5	4, 079	4, 355	4, 337	4, 257
12	4–12–4	13. 27	12. 56	15. 23	13. 69	16. 9	15. 6	14. 5	15. 7	4, 484	3, 918	4, 415	4, 272
13	4–8–8	13. 27	13. 01	15. 89	14. 06	15. 9	15. 4	13. 1	14. 8	4, 220	4, 008	4, 164	4, 131
14	4–4–12	14. 75	13. 90	13. 38	14. 01	15. 4	15. 5	13. 6	14. 8	4, 544	4, 307	3, 640	4, 164
15	4–0–16	12. 23	11. 92	12. 19	12. 11	15. 6	14. 7	13. 7	14. 7	3, 815	3, 503	3, 340	3, 553
16	0–20–0	13. 61	12. 46	15. 15	13. 74	14. 6	15. 6	13. 6	14. 6	3, 974	3, 888	4, 120	3, 994
17	0–16–4	12. 18	14. 39	13. 53	13. 37	16. 3	15. 3	14. 0	15. 2	3, 969	4, 403	3, 787	4, 053
18	0–12–8	12. 83	13. 74	14. 41	13. 66	13. 5	15. 3	14. 1	14. 3	3, 465	4, 205	4, 063	3, 911
19	0–8–12	13. 38	13. 26	12. 29	12. 98	15. 0	15. 6	13. 8	14. 8	4, 015	4, 136	3, 392	3, 848
20	0–4–16	13. 38	12. 75	12. 86	13. 00	15. 4	14. 8	12. 0	14. 1	4, 120	3, 775	3, 086	3, 660
21	0–0–20	12. 34	11. 98	10. 57	11. 63	15. 9	14. 7	12. 5	14. 4	3, 925	3, 522	2, 643	3, 363
	Average of checks	12. 47	12. 02	10. 59	11. 69	15. 3	15. 2	13. 2	14. 6	3, 816	3, 656	2, 794	3, 422

When the results of all these tests are averaged, it is seen that the 4–16–0 fertilizer mixture produced the largest yields per acre. However, there were pronounced fluctuations in the various tests. The highest acre yield of beets at Rocky Ford was produced with the 12–4–4 mixture, at Wiley with the 4–16–0 mixture, and at Lamar with the 4–8–8 mixture. The effect of the different fertilizer mixtures applied was apparently reflected in the increase or decrease in tonnage rather than in the percentage of sucrose in the beets. The plots receiving the 4–12–4 mixture produced on an average the highest testing beets. This result, however, can only be considered in the nature of a trend.

In pounds of sugar produced per acre the 12–4–4 mixture gave the best results at Rocky Ford, the 0–16–4 combination was the best at Wiley, and the 4–12–4 at Lamar. However, when the average result in pounds of sugar per acre was considered for the valley, the 4–12–4 fertilizer mixture proved most desirable. From these tests it is concluded that a fertilizer mixture containing nitrogen produces the best results on lighter textured soils, whereas a mixture relatively low in nitrogen but high in phosphoric acid gives the highest yields of sugar per acre on heavier textured soils.

In 1923 the plots were located at Rocky Ford, on the Las Animas clay loam soil type. This field had previously been treated with a heavy application of filter-press lime to flocculate the heavy soil. The area per plot and amount of plant food applied was the same as in the experimental-plot work conducted in 1922. The results of this experiment are summarized in table 2.

TABLE 2.—*Results of applying fertilizer to sugar beets at the rate of 75 pounds plant food per acre at Rocky Ford, Colo., 1923*

Treatment no.	Mixture N-P_2O_5-K_2O	Yield of beets per acre	Sucrose	Sugar production per acre	Treatment no.	Mixture N-P_2O_5-K_2O	Yield of beets per acre	Sucrose	Sugar production per acre
		Tons	*Percent*	*Pounds*			*Tons*	*Percent*	*Pounds*
1	20–0–0	8.83	12.5	2,207	13	4–8–8	9.94	15.4	3,062
2	16–4–0	9.44	13.1	2,472	14	4–4–12	7.62	15.0	2,285
3	16–0–4	11.25	13.6	3,061	15	4–0–16	11.56	13.1	3,029
4	12–8–0	11.00	13.8	3,036	16	0–20–0	11.06	15.0	3,317
5	12–4–4	9.30	14.5	2,696	17	0–16–4	11.86	13.7	3,249
6	12–0–8	10.28	15.1	3,105	18	0–12–8	10.43	14.1	2,940
7	8–12–0	9.64	14.7	2,833	19	0–8–12	10.56	14.0	2,957
8	8–8–4	11.06	14.4	3,185	20	0–4–16	9.36	15.2	2,844
9	8–4–8	8.70	14.1	2,455	21	0–0–20	10.43	13.6	2,838
10	8–0–12	11.39	13.0	2,961					
11	4–16–0	12.55	13.8	3,463					
12	4–12–4	13.11	14.1	3,696		Average of unfertilized checks	10.50	14.2	2,982

The largest yields on this clay loam soil were produced on the plots fertilized with the 4–12–4 and 4–16–0 mixtures. In general, the percentage of sucrose in the beets was depressed by the application of fertilizer mixture in which the percentage of nitrogen exceeded 8 percent, the 12–0–8 mixture being an exception. On the basis of pounds of sugar per acre, the plots fertilized with the 4–12–4 mixture produced the best results. It is observed that usually as the percentage of nitrogen in the fertilizer mixture was increased above 4 percent, the yield of sugar per acre was depressed.

In 1925 the last triangle experiment was located at Rocky Ford, on Rocky Ford fine sandy loam (table 3). The plots were one-fourth acre each, 8 rows wide, and 817 feet long, and had rows 20 inches apart. Sixty pounds of plant food or 300 pounds of a 20-percent mixture was applied per acre.

TABLE 3.—*Results of applying fertilizer to sugar beets at the rate of 60 pounds of plant food per acre at Rocky Ford, Colo., 1925*

Treatment no.	Mixture N-P_2O_5-K_2O	Yield of beets per acre	Sucrose	Sugar production per acre	Treatment no.	Mixture N-P_2O_5-K_2O	Yield of beets per acre	Sucrose	Sugar production per acre
		Tons	*Percent*	*Pounds*			*Tons*	*Percent*	*Pounds*
1	20–0–0	5.36	12.2	1,307	13	4–8–8	10.97	14.1	3,092
2	16–4–0	7.22	13.2	1,905	14	4–4–12	9.46	13.9	2,629
3	16–0–4	6.51	13.3	1,731	15	4–0–16	9.54	13.2	2,520
4	12–8–0	10.75	14.1	3,030	16	0–20–0	14.48	13.1	3,794
5	12–4–4	8.83	13.0	2,296	17	0–16–4	15.00	13.8	4,140
6	12–0–8	8.49	13.1	2,224	18	0–12–8	12.13	13.7	3,324
7	8–12–0	10.73	13.9	2,982	19	0–8–12	10.82	13.7	2,965
8	8–8–4	11.35	13.6	3,086	20	0–4–16	11.13	14.4	3,207
9	8–4–8	9.80	13.1	2,567	21	0–0–20	7.91	14.3	2,260
10	8–0–12	8.96	13.1	2,346					
11	4–16–0	14.78	14.0	4,138		Average of checks	10.48	13.7	2,864
12	4–12–4	13.21	14.1	3,724					

In this experiment the highest yields of beets were produced on the plots fertilized with the 0–16–4 and 4–16–0 mixtures, and the lowest yields were obtained from plots which had been fertilized with mixtures in which the percentage of nitrogen predominated. No consistent trends were obtained for percentage of sucrose as related to the kind of fertilizer mixture applied. In general, the results indicate that the mixtures in which the percentage of nitrogen predominated had a depressing effect on the percentage of sucrose in the beets. The yield of sugar per acre followed closely the trend shown for the beet tonnage.

When the yields of beets for the six complete-fertilizer experiments are averaged (differences in the plant food used per acre in the 4 years being disregarded) and the results assembled diagrammatically in figure 1, it is seen that the yield of beets is largest in those plots receiving an application of fertilizer mixtures containing a high percentage of phosphoric acid. The 4–16–0, 0–16–4, 0–20–0, and 4–12–4 mixtures produced the best results. When the amount of nitrogen in the mixture exceeded 4 percent, the germination and the yield were retarded. From this exploratory work, it is seen that the greatest response to fertilizer is in the high-phosphate portion of the triangle. This indicates that the fertilizer mixture likely to give the best results on these soils is one predominantly high in phosphoric acid. If the methods of cropping and handling each soil type were uniform throughout the valley, specific recommendations might be made. The results from the use of a fertilizer mixture shown by the averages in figure 1 may not apply in certain individual fields, since methods of cropping and soil management frequently influence the crop yields as much as the deficiencies in plant food which are supplied by the use of commercial fertilizers.

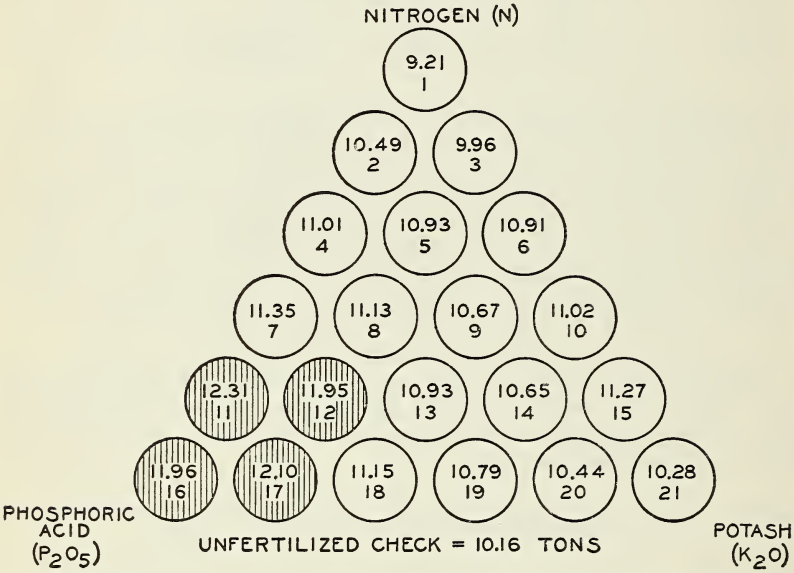

FIGURE 1.—Diagram showing the average yields in complete-triangle experiments with fertilizer combinations used in the fertilizer tests in the Arkansas Valley area, Colo., in 1921, 1922, 1923, and 1925. The upper figure in each circle denotes the average yield in tons of beets per acre and the lower figure, the mixture used, as listed below. Yields in the shaded area are significantly higher than those in the unfertilized checks, a difference of 1.53 tons being considered significant. The highest yields occur in the higher phosphate group of the triangle. The mixture numbers and fertilizer mixtures used were as follows: 1, 20–0–0; 2, 16–4–0; 3, 16–0–4; 4, 12–8–0; 5, 12–4–4; 6, 12–0–8; 7, 8–12–0; 8, 8–8–4; 9, 8–4–8; 10, 8–0–12; 11, 4–16–0; 12, 4–12–4; 13, 4–8–8; 14, 4–4–12; 15, 4–0–16; 16, 0–20–0; 17, 0–16–4; 18, 0–12–8; 19, 0–8–12; 20, 0–4–16; 21, 0–0–20.

TESTS WITH OUTSTANDING FERTILIZER MIXTURES

The results which were obtained from the experimental work conducted in 1922 show that fertilizer mixtures high in phosphoric acid produced the largest yields of sugar beets. These early results, however, were not uniform as to fertilizer response, indicating that other sources of plant food in addition to phosphoric acid might be required.

In 1923 the more promising mixtures were studied. Four experiments were located at Rocky Ford, Wiley, Lamar, and Morse, on the Las Animas clay, Prowers clay loam, Prowers clay loam, poorly drained phase, and Manvel silt loam, respectively. The plots were one-twentieth acre each, 4 rows wide, and 327 feet long, with the rows 20 inches apart, and fertilizers were applied at the rate of 75 pounds of plant food per acre (table 4).

Table 4.—*Results of applying fertilizer to sugar beets at the rate of 75 pounds of plant food per acre, at Rocky Ford, Wiley, Lamar, and Morse, Colo., 1923*

Mixture ($N-P_2O_5-K_2O$)	Yield of beets per acre					Sucrose					Sugar production per acre				
	Rocky Ford	Wiley	Lamar	Morse	Average	Rocky Ford	Wiley	Lamar	Morse	Average	Rocky Ford	Wiley	Lamar	Morse	Average
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
0–20–0	12.31	14.03	14.76	14.17	13.82	13.3	11.7	12.2	12.7	12.5	3,274	3,282	3,601	3,599	3,439
4–16–0	12.55	15.45	12.29	12.75	13.26	13.8	11.5	11.9	12.0	12.3	3,463	3,553	2,924	3,061	3,250
0–16–4	11.86	15.37	13.52	14.04	13.70	13.7	11.8	12.5	12.4	12.6	3,249	3,628	3,380	3,483	3,435
4–12–4	13.11	15.78	13.16	13.30	13.84	14.1	11.7	12.9	12.8	12.9	3,696	3,691	3,395	3,404	3,547
8–8–4	11.06	15.27	11.04	12.98	12.59	14.4	11.7	11.3	11.8	12.3	3,185	3,573	2,495	3,063	3,079
4–8–8	9.94	15.53	13.36	11.19	12.51	15.4	11.8	12.6	13.1	13.2	3,062	3,664	3,365	2,932	3,256
12–4–4	9.30	14.40	10.71	7.93	10.59	14.5	12.5	13.2	10.0	12.6	2,696	3,600	2,828	1,586	2,678
8–4–8	6.71	14.30	13.00	8.39	10.60	14.1	11.9	13.6	10.4	12.5	2,455	3,404	3,536	1,745	2,785
4–4–12	7.62	14.70	12.70	11.56	11.65	15.0	11.8	12.8	11.6	12.8	2,285	3,469	3,251	2,683	2,922
Average of checks	11.31	13.86	12.97	9.15	11.82	14.2	12.1	11.7	11.8	12.5	3,215	3,359	3,036	2,160	2,943

The average results of the experiments on these four soil types demonstrate that the 4–12–4 and 0–20–0 mixtures produced the largest yields of beets. The 4–12–4 mixture produced the largest yields at Rocky Ford and Wiley, and the 0–20–0 mixture produced the largest yields at Lamar and Morse. No consistent relationship was obtained between percentage of sucrose in the beet and the kind of fertilizer applied. The yield of sugar per acre followed the same trend as the beet tonnage.

In 1924 the rate of plant food applied in the fertilizer mixture was reduced to 60 pounds per acre (table 5). Ten experiments were made, 1 each at Rocky Ford, Las Animas, Fort Lyon, McClave, Wiley, and Sugardale, 2 at May Valley, and 1 each at Kornman and Morse, on 6 major soil types. The plots were one-fourth acre each, 8 rows wide, and 817 feet long, with rows 20 inches apart.

TABLE 5.—*Results of applying fertilizer at the rate of 60 pounds per acre to sugar beets at 10 locations on 6 soil types in the Arkansas Valley in Colorado, 1924*

YIELD OF BEETS PER ACRE

(Mixture N-P_2O_5-K_2O)	Rocky Ford,[1] Rocky Ford fine sandy loam	Las Animas, Fort Lyon clay loam	Fort Lyon, Rocky Ford clay loam	McClave, Prowers clay loam	Wiley, Prowers clay loam, poorly drained phase	Sugardale, Prowers loam	May Valley, Prowers clay loam		Kornman, Prowers loam	Morse, Manvel silt loam	Average[1]
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
0–20–0	7. 59	13. 46	13. 79	15. 99	16. 67	14. 28	16. 03	7. 12	14. 14	10. 81	13. 59
0–16–4		12. 01	15. 36	16. 45	16. 32	12. 69	14. 86	8. 03	15. 14	9. 87	13. 41
4–16–0		12. 68	11. 59	16. 70	14. 67	15. 38	16. 13	7. 41	13. 77	10. 92	13. 25
4–12–4	8. 02	14. 33	13. 12	13. 97	16. 06	14. 48	17. 46	8. 58	15. 17	9. 16	13. 59
Average of checks	7. 88	11. 69	12. 33	10. 27	13. 25	13. 00	16. 82	7. 00	11. 85	8. 33	11. 62

SUCROSE

(Mixture N-P_2O_5-K_2O)	Rocky Ford,[1] Rocky Ford fine sandy loam	Las Animas, Fort Lyon clay loam	Fort Lyon, Rocky Ford clay loam	McClave, Prowers clay loam	Wiley, Prowers clay loam, poorly drained phase	Sugardale, Prowers loam	May Valley, Prowers clay loam		Kornman, Prowers loam	Morse, Manvel silt loam	Average[1]
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
0–20–0	16. 0	18. 2	15. 9	16. 2	11. 7	17. 3	15. 5	14. 4	18. 2	19. 0	16. 27
0–16–4		18. 5	16. 1	16. 6	11. 1	16. 9	16. 3	15. 1	17. 3	20. 3	16. 47
4–16–0		18. 3	16. 6	15. 9	11. 4	17. 3	17. 2	15. 2	15. 9	19. 5	16. 37
4–12–4	16. 2	17. 7	15. 9	16. 8	12. 3	17. 6	16. 2	14. 8	15. 8	20. 2	16. 37
Average of checks	15. 5	17. 4	15. 3	15. 9	11. 6	16. 1	16. 5	14. 8	14. 9	18. 8	15. 70

SUGAR PRODUCTION PER ACRE

(Mixture N-P_2O_5-K_2O)	Rocky Ford,[1] Rocky Ford fine sandy loam	Las Animas, Fort Lyon clay loam	Fort Lyon, Rocky Ford clay loam	McClave, Prowers clay loam	Wiley, Prowers clay loam, poorly drained phase	Sugardale, Prowers loam	May Valley, Prowers clay loam		Kornman, Prowers loam	Morse, Manvel silt loam	Average[1]
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
0–20–0	2, 427	4, 898	4, 384	5, 182	3, 900	4, 940	4, 968	2, 049	5, 148	4, 108	4, 397
0–16–4		4, 442	4, 944	5, 462	3, 623	4, 288	4, 845	2, 424	5, 222	4, 007	4, 362
4–16–0		4, 642	3, 847	5, 312	3, 345	5, 323	5, 549	2, 253	4, 380	4, 253	4, 323
4–12–4	2, 694	5, 072	4, 174	4, 682	3, 950	5, 096	5, 657	2, 540	4, 793	3, 700	4, 407
Average of checks	2, 447	4, 061	3, 773	3, 269	3, 068	4, 169	5, 543	2, 077	3, 542	3, 139	3, 627

[1] Rocky Ford not included in averages.

When the average of the nine experiments is taken (excluding Rocky Ford), equal yields of beets were produced on plots fertilized with the 0–20–0 and the 4–12–4 mixture. Individually considered, the 0–16–4 mixture produced the highest yields at Fort Lyon, the 4–16–0 mixture was best at McClave, Sugardale, and Morse; the 4–12–4 mixture gave the largest yields at Rocky Ford, Las Animas, May Valley, and Kornman, and the 0–20–0 mixture was the best at Wiley. On an average, a slightly higher percentage of sucrose was obtained from beets fertilized with the 0–16–4 mixture. In pounds of sugar per acre, the 4–12–4 mixture produced the highest average yields. Individually considered, 5 of the 10 experiments showed differences in favor of the 4–12–4 mixture, 3 in favor of the 0–16–4 mixture, and 2 in favor of the 4–16–0 mixture.

In 1925, 4 fertilizer experiments were located at Avondale, Manzanola, Rocky Ford, and Las Animas, 1 on Rocky Ford loam, 2 on Rocky Ford fine sandy loam, and 1 on Fort Lyon clay loam. The plots were one-fourth acre each, 8 rows wide, and 817 feet long. The rows were 20 inches apart, and 60 pounds of plant food per acre were applied (table 6).

TABLE 6.—*Results of applying fertilizer to sugar beets at the rate of 60 pounds of plant food per acre at Avondale, Manzanola, Rocky Ford, and Las Animas, Colo., 1925*

ACRE YIELD OF BEETS

Mixture ($N-P_2O_5-K_2O$)	Avondale	Manzanola [1]	Rocky Ford	Las Animas	Average
	Tons	*Tons*	*Tons*	*Tons*	*Tons*
0-20-0	17.12	15.23	14.48	12.84	14.92
4-16-0	19.28	13.64	14.78	10.23	14.49
0-16-4	17.85	14.50	15.00	12.11	14.87
4-12-4	16.02	15.42	12.68	9.70	13.46
8- 8-4	13.64	13.41	11.35	9.72	12.03
4- 8-8	15.83	15.86	10.97	8.82	12.87
Average of checks	16.52	14.96	8.90	6.94	11.83

SUCROSE

Mixture ($N-P_2O_5-K_2O$)	Avondale	Manzanola [1]	Rocky Ford	Las Animas	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
0-20-0	14.1	16.6	13.1	8.8	13.2
4-16-0	14.2	18.1	14.0	8.5	13.7
0-16-4	14.0	16.9	13.8	9.4	13.5
4-12-4	13.2	16.2	14.6	8.1	13.0
8- 8-4	13.5	16.8	13.6	9.3	13.3
4- 8-8	13.7	16.9	14.1	9.2	13.5
Average of checks	13.4	16.3	14.1	9.3	13.3

SUGAR PRODUCTION PER ACRE

Mixture ($N-P_2O_5-K_2O$)	Avondale	Manzanola [1]	Rocky Ford	Las Animas	Average
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0-20-0	4,829	5,055	3,794	2,261	3,985
4-16-0	5,477	4,937	4,138	1,738	4,073
0-16-4	5,011	4,900	4,140	2,276	4,082
4-12-4	4,228	4,995	3,703	1,571	3,624
8- 8-4	3,683	4,507	3,086	1,809	3,271
4- 8-8	4,337	5,362	3,092	1,623	3,604
Average of checks	4,436	4,884	2,514	1,309	3,285

[1] No irrigation water was applied to this field until 3 weeks after it was planted.

The 4–16–0 mixture produced the largest yields at Avondale, the 4–8–8 mixture the largest at Manzanola, the 0–16–4 mixture the largest at Rocky Ford, and the 0–20–0 the largest at Las Animas. The differences in percentage of sucrose were on an average too small to warrant drawing conclusions. On the basis of sugar per acre, the plots fertilized with the 0–16–4 mixture produced slightly higher yields at Rocky Ford and Las Animas. The 4–16–0 mixture was the best at Avondale, and the 4–8–8 mixture was the best at Manzanola. The highest average yield of sugar from the four experiments was obtained with the 0–16–4 mixture.

In 1926 special mixtures were used in addition to those used in the previous experiments. Some of the more promising fertilizer mixtures were studied with greater precision, 2-percent differentiations in the formulas being used instead of the 4-percent differentiations previously used. Potassium ammonium phosphate (manufactured in the research laboratories of the Bureau of Chemistry and Soils) and Ammo-phos (Ammo-phos A) were also used in these experiments, equivalent to commercial mixtures of 1.6–14.1–4.3 and 4.3–16–0, respectively. The plots were one-eighth acre each, 8 rows wide, and 409 feet long, and the rows were 20 inches apart. The plantings were in duplicate, the results of which are shown in series 1 and 2 in table 7. The amount of plant food was increased to 80 pounds per acre. The experiment was located at Rocky Ford on the Rocky Ford fine sandy loam soil type. The results of this experiment are summarized in table 7.

TABLE 7.—*Results of applying fertilizer to sugar beets at the rate of 80 pounds of plant food per acre, Rocky Ford, Colo., 1926*

Mixture	Yield of beets per acre			Sucrose			Sugar production per acre		
	Series 1	Series 2	Average	Series 1	Series 2	Average	Series 1	Series 2	Average
	Tons	*Tons*	*Tons*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*
8–12–0	13. 98	15. 38	14. 68	14. 9	15. 6	15. 3	4, 166	4, 799	4, 483
4–16–0	11. 58	10. 70	11. 14	16. 8	15. 0	15. 9	3, 891	3, 210	3, 551
0–20–0	14. 05	10. 32	12. 19	15. 9	14. 5	15. 2	4, 468	2, 993	3, 731
0–18–2	13. 33	10. 12	11. 73	15. 5	15. 2	15. 4	4, 132	3, 076	3, 604
0–16–4	10. 71	11. 31	11. 01	15. 4	15. 9	15. 7	3, 299	3, 597	3, 448
2–18–0	11. 53	9. 78	10. 66	17. 1	15. 0	16. 1	3, 943	2, 934	3, 439
2–16–2	12. 47	11. 29	11. 88	16. 7	15. 4	16. 1	4, 165	3, 477	3, 821
4–12–4	13. 49	12. 06	12. 78	14. 5	15. 5	15. 0	3, 912	3, 739	3, 826
0–12–8	16. 20	12. 57	14. 39	17. 2	14. 2	15. 7	5, 573	3, 570	4, 572
4.3–16–0[1]	12. 69	13. 36	13. 03	16. 3	14. 7	15. 5	4, 137	3, 928	4, 033
0–14–6	13. 50	15. 09	14. 30	16. 5	14. 8	15. 7	4, 455	4, 467	4, 461
2–14–4	14. 98	13. 68	14. 33	15. 3	14. 1	14. 7	4, 584	3, 858	4, 221
1.6–14.1–4.3[2]	15. 00	15. 92	15. 46	16. 3	15. 4	15. 9	4, 890	4, 903	4, 897
4–14–2	14. 06	11. 82	12. 94	15. 9	16. 1	16. 0	4, 471	3, 806	4, 139
6–14–0	15. 39	12. 42	13. 91	16. 9	14. 0	15. 5	5, 202	3, 478	4, 340
2–12–6	14. 06	15. 36	14. 71	15. 8	14. 6	15. 2	4, 443	4, 485	4, 464
6–12–2	12. 57	14. 55	13. 56	13. 6	15. 3	14. 5	3, 419	4, 452	3, 936
Average of checks	11. 42	10. 81	11. 12	15. 5	14. 4	15. 0	3, 547	3, 124	3, 336

[1] Ammo-phos.
[2] Potassium ammonium phosphate.

The potassium ammonium phosphate mixture produced the best average yield of beets and of sugar per acre. The differences in percentage of sucrose were too small to be considered significant.

In 1927 two experiments were located at Avondale and Lamar, on the Rocky Ford fine sandy loam and Manvel silt loam soil types, respectively (table 8). The plots were one-fifth acre each in area, 8 rows wide, and 653 feet long, and the rows were 20 inches apart. The amount of plant food applied per acre was reduced to 32 pounds.

TABLE 8.—*Results of applying 32 pounds of plant food per acre to sugar beets at Avondale and Lamar, Colo., 1927*

Mixture	Yield of beets per acre		Sucrose		Sugar production per acre	
	Avondale	Lamar	Avondale	Lamar	Avondale	Lamar
	Tons	*Tons*	*Percent*	*Percent*	*Pounds*	*Pounds*
0–20–0	14. 41	12. 40	15. 5	16. 6	4, 468	4, 118
4–16–4	15. 18	11. 07	15. 0	16. 5	4, 555	3, 653
0–16–4	13. 10	11. 20	15. 2	15. 8	3, 982	3, 539
1.9–16–4.9[1]	14. 52	12. 06	15. 5	16. 8	4, 500	4, 051
4.3–16–0[2]	14. 08	11. 16	17. 0	16. 0	4, 789	3, 570
Average of checks	12. 21	11. 68	15. 0	15. 0	3, 655	3, 510

[1] Potassium ammonium phosphate.
[2] Ammo-phos.

The plots fertilized with the 4–16–4 mixture produced the highest yields of beets at Avondale, whereas at Lamar, the 0–20–0 mixture was the best. The percentage of sucrose in the beets was favorably influenced in the experiment at Avondale by the Ammo-phos fertilizer, and that at Lamar by the potassium ammonium phosphate fertilizer. The largest yields of sugar per acre were produced at Avondale from beets grown in plots fertilized with Ammo-phos, and at Lamar in plots fertilized with the 0–20–0 mixture.

In 1928 the experiments were located at Pueblo and Lamar on Rocky Ford fine sandy loam and Prowers clay soil types, respectively (table 9). The size of the plots and the amount of plant food applied per acre were the same as in the 1927 experiments.

TABLE 9.—*Results of applying 32 pounds of plant food per acre to sugar beets at Pueblo and Lamar, Colo., 1928*

Mixture	Yield of beets per acre		Sucrose		Sugar production per acre	
	Pueblo	Lamar	Pueblo	Lamar	Pueblo	Lamar
	Tons	*Tons*	*Percent*	*Percent*	*Pounds*	*Pounds*
0–20–0	10. 28	13. 98	17. 0	12. 2	3, 485	3, 385
4–16–0	11. 19	14. 62	17. 0	10. 5	3, 808	3, 056
0–16–4	10. 13	14. 12	17. 1	12. 6	3, 449	3, 547
4–12–4	10. 45	15. 05	17. 8	13. 8	3, 708	4, 145
1.6–14.1–4.3 [1]		14. 51		11. 2		3, 250
4.6–15.4–0 [2]		13. 30		9. 9		2, 634
5.8–9.1–5.1 [3]		14. 07		11. 7		3, 300
Average of checks	10. 12	13. 31	15. 8	11. 7	3, 202	3, 120

[1] Potassium ammonium phosphate.
[2] Ammo-phos.
[3] Nitrophoska.

The response to fertilizer was not pronounced in either experiment. The 4–16–0 mixture produced the largest tonnage of beets on the Pueblo plots, and the 4–12–4 mixture the largest tonnage at Lamar. The percentage of sucrose was highest in the plots fertilized with the 4–12–4 mixture. On the basis of sugar yield per acre, the 4–16–0 mixture gave the highest yield at Pueblo and the 4–12–4 mixture the highest at Lamar.

DISCUSSION

When the responses to certain fertilizer combinations used in tests conducted from 1922 through 1928 are considered, important relationships between soil types and the kind of fertilizer applied become apparent. For six of the major soil types on which beets are grown extensively, the fertilizer response was as follows; on the fine sandy loam soil types, the 4–16–0 and 4–12–4 fertilizer mixtures produced the largest yields of beets. On the silt loam and loam soil types, the 4–16–0 and 4–16–4 mixtures gave the best results. On the clay and clay loam types, the 0–20–0 and 0–16–4 mixtures produced the largest tonnage of beets.

In summarizing the results of all of the fertilizer experiments, it is seen that the plots fertilized with the 4–16–0 mixture produced an average of 13.35 tons of beets per acre; those fertilized with the 0–16–4 mixture, an average of 13.25 tons; and those fertilized with the 0–20–0 mixture, an average of 13.10 tons. The plots fertilized with the 4–12–4 mixture produced 13.03 tons of beets, and the untreated check yielded 11.43 tons of beets an acre. These differences resulting from applications of the commercial fertilizers listed correspond to increases of 1.92, 1.82, 1.67, and 1.60 tons of beets per acre over the yield of the unfertilized check. These results indicate the same close relationship between the 0–20–0 and 4–12–4 mixtures as is shown in figure 1.

TESTS OF SOURCES OF PLANT FOOD IN FERTILIZER MIXTURES

NITROGEN

Numerous tests were undertaken with various nitrogenous fertilizers. In the fertilizer mixtures described in this circular, nitrogen was derived from three sources—sodium nitrate, ammonium sulphate, and cottonseed meal—each fertilizer element being used in amounts sufficient to supply one-third of the nitrogen indicated. Special tests, however, had been conducted with nitrogen-bearing fertilizers to determine which source of nitrogen was the best for a given soil type. In 1922, 4 nitrogen-bearing fertilizers were tested, 2 derived from organic sources and 2 from inorganic sources. Cottonseed meal and dried blood represented the organic fertilizer materials and sodium nitrate and ammonium sulphate, the inorganic materials. The work was conducted at Rocky Ford, Wiley, and Lamar on Rocky Ford fine sandy loam, Prowers clay loam, and Prowers clay loam, poorly drained phase, respectively. The plots were one-twentieth acre each, 4 rows wide, and 327 feet long, and the rows were 20 inches apart. Seventy-five pounds of plant food per acre were applied in the row with the seed (table 10).

TABLE 10.—*Influence of source of nitrogen applied at the rate of 75 pounds of plan food in a 3–6–6 fertilizer mixture on the yield and quality of sugar beets, at Rocky Ford, Wiley, and Lamar, Colo., 1922*

Source of nitrogen	Yield of beets per acre				Sucrose				Sugar production per acre			
	Rocky Ford	Wiley	Lamar	Average	Rocky Ford	Wiley	Lamar	Average	Rocky Ford	Wiley	Lamar	Average
	Tons	*Tons*	*Tons*	*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Sodium nitrate	9.45	10.92	16.17	12.18	16.1	14.9	12.8	14.6	3,044	3,253	4,140	3,479
Ammonium sulphate	10.43	11.54	12.48	11.48	14.6	15.0	13.2	14.3	3,044	3,461	3,296	3,267
Cottonseed meal	11.51	10.72	14.81	12.35	15.8	14.9	13.7	14.8	3,637	3,193	4,058	3,629
Dried blood	12.54	11.17	14.22	12.64	15.2	15.0	12.7	14.3	3,812	3,350	3,611	3,591
Average of checks	10.24	8.73	10.00	9.66	15.7	15.3	11.9	14.3	3,225	2,671	2,377	2,758

The organic nitrogen derived from dried blood and from cottonseed meal gave the highest average yields of beets. Considering the individual results, plots fertilized with dried blood gave the best results at Rocky Ford on the lighter textured soil. On the heavier textured soils represented in the Wiley and Lamar plots, the inorganic fertilizer produced the largest yields; ammonium sulphate produced the largest at Wiley, and sodium nitrate the largest at Lamar. The differences in percentages of sucrose were too small to be significantly attributed to the effect of the mixture. In yield of sugar per acre, the individual results follow closely the trend indicated for beet tonnage, but the average results are strongly in favor of the nitrogen derived from organic sources. However, the use of nitrogen derived from organic sources, such as cottonseed meal, tankage, and similar by-products, used for fertilizer purposes, is not always practicable in the West owing to the generally higher cost per unit of organic nitrogen, occasioned by the low percentage of nitrogen in these by-products, and the increased demand for them for use in the feeding of livestock. Of the inorganic sources of nitrogen, ammonium sulphate and sodium nitrate, the former produced a greater tonnage of beets per acre in 2 out of 3 experiments.

In 1923 special fertilizer mixtures containing cyanamid and sodium nitrate as sources of nitrogen were compared. The experiment was located at Rocky Ford on Rocky Ford fine sandy loam. Seventy-five pounds of plant food were applied per acre. The plots were one-twentieth acre each, 4 rows wide, and 327 feet long, and the rows were 20 inches apart (table 11). As the primary purpose of this experiment was to compare the 2–13–0, 2–13–2, 2–13–4, and 2–13–6 mixtures, the amount of plant food was held constant at 75 pounds per acre.

TABLE 11.—*Results obtained with special fertilizer mixtures applied at the rate of 75 pounds of plant food per acre to sugar beets at Rocky Ford, Colo., 1923*

Plot	Mixture	Yield of beets per acre	Sucrose	Sugar production per acre
		Tons	*Percent*	*Pounds*
A [1]	2–13–0	12.47	13.7	3,417
B [2]	2–13–0	12.39	12.8	3,172
A [1]	2–13–2	13.01	14.3	3,822
B [2]	2–13–2	13.76	13.6	3,734
A [1]	2–13–4	10.35	13.5	2,795
B [2]	2–13–4	12.16	13.2	3,210
A [1]	2–13–6	11.53	12.8	2,952
B [2]	2–13–6	12.97	12.8	3,320
Average of checks		10.47	12.1	2,534

[1] Nitrogen derived from cyanamid.
[2] Nitrogen derived from sodium nitrate.

The plots fertilized with mixtures in which the source of nitrogen was sodium nitrate outyielded in 3 out of the 4 experiments the plots which were fertilized with mixtures containing cyanamid. In 3 out of 4 cases a higher sucrose content in the beets was obtained from plots fertilized with a mixture in which cyanamid was the source of nitrogen. However, when production of sugar per acre is considered, the plots fertilized with mixtures containing sodium nitrate outyielded by approximately 3 percent those plots which were fertilized with mixtures containing cyanamid. The use of cyanamid in the fertilizer mixture in excess of 80 pounds per ton is not generally recommended, since it especially reacts with superphosphate.

PHOSPHORIC ACID

The source of phosphoric acid in the fertilizer mixture received considerable attention in the experiments. From 1923 to 1927, inclusive, 20 tests with superphosphate (16 percent P_2O_5) and treble superphosphate (44 to 45 percent P_2O_5) were conducted in various localities in the Arkansas Valley area to determine which phosphate material was the more effective source of phosphoric acid (table 12). The plot arrangments were the same as in the previously reported more comprehensive experiments (tables 2 to 9) in which these two sources of phosphoric acid had been tested.

TABLE 12.—*Comparison of superphosphate (16 percent* P_2O_5*) and treble superphosphate (44 percent* P_2O_5*) as a source of plant food,*[1] *Arkansas Valley area, Colo.*

Year and percentage of P_2O_5	Yield of beets per acre	Sucrose	Sugar production per acre
	Tons	*Percent*	*Pounds*
1923 (average of 4 tests):			
16 percent	13. 82	12. 5	3, 439
44 percent	13. 67	12. 3	3, 289
1924 (average of 10 tests):			
16 percent	12. 99	16. 2	4, 200
44 percent	12. 46	16. 1	3, 967
1925 (average of 4 tests):			
16 percent	14. 92	13. 2	3, 983
44 percent	13. 71	12. 8	3, 538
1926:			
16 percent	12. 19	15. 2	3, 731
44 percent	10. 96	14. 7	3, 241
1927:			
16 percent	15. 31	15. 0	4, 577
44 percent	13. 70	15. 1	4, 121
Summary of results (for 5 years):			
16 percent	13. 85	14. 4	3, 986
44 percent	12. 90	14. 2	3, 631

[1] Equal amounts of P_2O_5 in each source of phosphate material were compared.

It is noted that in each of the 5 years the larger beet yields were obtained from the plots fertilized with the 16-percent superphosphate. Similarly, with but one exception, a slightly higher percentage of sucrose in the beet was produced from the plots fertilized with the superphosphate. In production of sugar, the yields followed the trend shown by the beet tonnage. When the average of the results obtained in these 20 tests is considered, the plots fertilized with superphosphate are found to have outyielded the plots fertilized with treble superphosphate by approximately 9 percent in pounds of sugar per acre.

The consistency with which plots fertilized with superphosphate outyielded those fertilized with treble superphosphate led to a series of experiments to determine the effect of diluting treble superphosphate by adding filter-press lime[6] as a filler so as to make a mixture equivalent to a 16 percent superphosphate. The reason for using filter-press lime instead of gypsum, which is the chief constituent in superphosphate, was to neutralize the excess acidity which was present in the treble superphosphate as manufactured at that time. The treble superphosphate now being manufactured would not show this highly acid condition as the process of manufacture has been improved.

In field experiments conducted on several soil types in different localities treble superphosphate was compared with the same product sufficiently diluted with filter-press lime to be equivalent to 16-percent superphosphate. The results are shown in table 13.

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[6] The filler used was filter-press lime, a waste product resulting from the processing of beet sugar, containing approximately 83 percent of calcium carbonate.

TABLE 13.—*Tests in diluting treble superphosphate with filter-press lime Arkansas Valley area, Colo.*

Year and fertilizer material	Average yield of beets per acre	Average percentage of sucrose	Average sugar production per acre
	Tons	*Percent*	*Pounds*
1924 (10 tests):			
Treble superphosphate	12.46	16.1	3,963
Treble superphosphate+lime	13.23	16.3	4,313
1925 (4 tests):			
Treble superphosphate	13.71	12.8	3,538
Treble superphosphate+lime	13.97	13.0	3,658
Summary of results:			
Treble superphosphate	13.09	14.5	3,750
Treble superphosphate+lime	13.60	14.7	3,986

On an average the addition of filter-press lime to the treble superphosphate increased the beet yield 0.51 ton per acre, or 4 percent; the percentage of sucrose in the beets was increased 0.2 percent, and the yield of sugar increased 236 pounds, or 6 percent per acre over that produced on plots fertilized with treble superphosphate undiluted. The phosphoric acid in the fertilizer may possibly be affected by the presence of an excess of sodium salts in the soil, a condition which occurs quite generally in many irrigated soils of the Arkansas Valley area. The average content of solids (chiefly sodium and calcium sulphate) in the irrigation water during the irrigating season was approximately 127 and 254 parts per 100,000 at Rocky Ford and Lamar, respectively.[7] The irrigation waters were also highly charged with colloidal material from different soil formations, which may influence the efficiency of different phosphate materials.[8]

The continued use of irrigation water highly impregnated with mixed alkali salts is certain to result eventually in the accumulation of these salts in the soil in amounts sufficient to reduce the available lime, and when this occurs the needs of the crop for lime must be met either by using a commercial fertilizer or by lightly top-dressing the soil with lime.

POTASH

Sulphate of potash was used exclusively in the mixtures which contained potash. While in many cases the 0–16–4 mixture gave good results, it was not shown by use of the triangle method of experimentation that potash was one of the important plant-food requirements for successful sugar-beet growing in the Arkansas Valley area.

DISCUSSION

Considering the fact that in the Arkansas Valley area fertilizer mixtures high in phosphoric acid are required for best results, the sources of plant food in such mixtures are important. It had previously been shown that soil type influenced to a marked degree the crop response to an application of commercial fertilizer. This relationship is further emphasized by the results of these tests which show that the kind of material used has a pronounced influence on the efficiency of the fertilizer.

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[7] SKUDERNA, A. W., and MICKEL, C. E. ARKANSAS RIVER WATER ANALYSIS. Amer. Beet Sugar Co. Research Repts., 119 pp., illus. 1921.

[8] GILE, P. L. THE EFFECT OF DIFFERENT COLLOIDAL SOIL MATERIALS ON THE EFFICIENCY OF SUPERPHOSPHATE. U.S. Dept. Agr. Tech. Bull. 371, 50 pp., illus. 1933.

From these tests it would appear that the nitrogen in the fertilizer mixture should be derived from both organic and inorganic materials. The phosphoric acid required may be supplied either by superphosphate or by treble superphosphate to which lime may be added as a filler if necessary. The need for potash was not fully determined, and therefore the kinds of potash-bearing materials required in a complete fertilizer were not investigated in detail. Such preliminary indications as were obtained were not sufficiently striking to warrant the drawing of conclusions.

TESTS OF SPECIAL RATES OF FERTILIZER APPLICATION

The amount of fertilizer required by the beet crop has been extensively studied abroad, where as much as 1,000 pounds of a mixed fertilizer is generally applied per acre. Experiments conducted in Michigan indicate that from 400 to 600 pounds of a complete fertilizer produce the best average results.[9]

In the Arkansas Valley area, the preliminary experiments conducted in 1921 were based on a 1,000-pound application of fertilizer containing 150 pounds of plant food per acre. This amount was reduced to 75 pounds in 1922 and was further reduced when results of experimental work justified such action.

COMPLETE FERTILIZER MIXTURES

In 1922, tests were conducted at Rocky Ford and Lamar with a 2–14–2 mixture. In these tests 90, 180, and 360 pounds of plant food per acre were applied and comparisons made with the unfertilized check (table 14). The plots were located on Rocky Ford fine sandy loam and Prowers clay loam soil types, respectively. Each plot was one-twentieth acre in area, 4 rows wide, and 327 feet long, and the rows were 20 inches apart.

Another study was conducted in 1922 at Rocky Ford, Wiley, and Lamar, on the same soil types as those in the 2–14–2 test. The plot areas were also the same. The 3–6–6 mixture was used at rates varying from 37.5 to 150 pounds of plant food per acre.

By 1925 the results of previous experiments indicated that of the complete fertilizers the 4–12–4 mixture was the most effective. Accordingly, tests were conducted with it at Rocky Ford at rates varying from 30 to 150 pounds of plant food per acre. The plots were one-fourth acre in size, 8 rows wide, and 817 feet long, with rows 20 inches apart, and were located on Rocky Ford fine sandy loam.

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[9] TYSON, J., and MCCOOL, M. M. SOIL FERTILIZATION FOR SUGAR BEETS. Mich. Agr. Expt. Sta. Spec. Bull. 205, 31 pp., illus. 1930.

TABLE 14.—*Results of applying a complete fertilizer mixture to sugar beets at Rocky Ford, Lamar, and Wiley, Colo., 1922, 1923, and 1925*

Location, year, and mixture	Plant-food rate per acre	Yield of beets per acre	Sucrose	Sugar production per acre
Rocky Ford, 1922:	*Pounds*	*Tons*	*Percent*	*Pounds*
2–14–2	90	13. 60	14. 3	3, 890
2–14–2	180	13. 68	13. 2	3, 610
2–14–2	360	12. 89	13. 7	3, 531
Average of checks		12. 78	15. 3	3, 912
Lamar, 1922:				
2–14–2	90	17. 48	13. 1	4, 581
2–14–2	180	20. 84	14. 1	5, 876
2–14–2	360	15. 15	13. 5	4, 090
Average of checks		10. 03	13. 7	2, 751
Rocky Ford, 1922:				
3–6–6	37. 5	11. 43	15. 4	3, 520
3–6–6	75. 0	12. 80	16. 3	4, 173
3–6–6	150. 0	12. 05	15. 8	3, 809
Average of checks		10. 64	15. 8	3, 361
Wiley, 1922:				
3–6–6	37. 5	9. 48	15. 0	2, 844
3–6–6	75. 0	10. 73	15. 1	3, 239
3–6–6	150. 0	11. 49	15. 8	3, 630
Average of checks		8. 82	14. 1	2, 486
Lamar, 1922:				
3–6–6	37. 5	11. 45	14. 3	3, 234
3–6–6	75. 0	13. 05	14. 7	3, 794
3–6–6	150. 0	13. 52	14. 6	3, 876
Average of checks		11. 29	14. 6	3, 301
Rocky Ford, 1923:				
2–14–2	37. 5	11. 11	13. 1	2, 911
2–14–2	75. 0	9. 65	12. 5	2, 413
2–14–2	150. 0	9. 80	11. 7	2, 293
Average of checks		10. 47	12. 1	2, 534
Rocky Ford, 1925:				
4–12–4	30	13. 05	13. 8	3, 602
4–12–4	60	12. 69	14. 6	3, 703
4–12–4	90	11. 83	14. 1	3, 335
4–12–4	120	10. 79	13. 7	2, 957
4–12–4	150	10. 40	13. 1	2, 724
Average of checks		12. 60	13. 2	3, 303

On comparing the beet yields obtained in the tests in which the 2–14–2 fertilizer mixture was used, it is evident that the most efficient utilization of the fertilizer was obtained on the Lamar plots. This field was in a very high state of fertility, having been covered frequently and heavily with high-quality sheep manure. These results substantiate the observations of others [10], and emphasize the need for organic matter in the soil if the commercial fertilizer applied is to be most effectively utilized. The 180-pound rate of plant food produced the best results at Lamar. At Rocky Ford the effect of the 90-pound application was approximately equal to 180 pounds of plant food, but neither rate of application was very effective when compared with the results on the untreated check. The test conducted in 1925 at Rocky Ford shows that the best yields were obtained from plots receiving an application of 30 pounds of plant food per acre and that there was a consistent reduction in tonnage as the rate of application of plant food was increased. The 3–6–6 mixture was too low in phosphoric acid for the soil types considered, to permit an adequate evaluation of the rate of application of the plant food. However, the 75-pound rate proved best at Rocky Ford, and the 150-pound rate gave the best results at Wiley and Lamar.

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[10] See footnote 9, p. 16.

No consistent differences were observed between the rate of plant food application and the percentage of sucrose in the beets. In the production of sugar per acre, the yields follow closely those already shown for beet tonnage.

PHOSPHORIC ACID

Inasmuch as many of the commercial beet fields responded to an application of phosphoric acid alone, tests were conducted with superphosphate to determine the best rate of applying it. Tests were conducted at Rocky Ford in 1925 on Rocky Ford fine sandy loam, from 30 to 150 pounds of plant food being applied per acre in 30-pound multiples. In 1927 the maximum application was reduced to 80 pounds, with 12- to 16-pound gradations in the rate of application (except at Rocky Ford). The plots were located at Avondale, Rocky Ford, and Lamar, on Rocky Ford fine sandy loam and Prowers clay loam, respectively. The plots were one-fourth acre in area, 8 rows wide, and 817 feet long, with the rows 20 inches apart. In 1928 plots of the same size were again located on the same soil types at Rocky Ford and Lamar (table 15).

TABLE 15.—*Results of applying 0–20–0 fertilizer to sugar beets at Rocky Ford, Avondale, and Lamar, Colo., 1925, 1927, and 1928*

Location and plant-food rate per acre (pounds)	Yield of beets per acre	Sucrose	Sugar production per acre
	Tons	*Percent*	*Pounds*
Rocky Ford, 1925:			
30	11.82	13.1	3,096
60	14.48	13.1	3,794
90	14.87	13.2	3,926
120	13.85	13.3	3,685
150	13.17	12.6	3,318
Average of checks	12.60	13.2	3,303
Avondale, 1927:			
20	13.33	15.3	4,080
32	14.41	15.5	4,468
48	14.25	15.7	4,475
64	15.01	15.3	4,593
Average of checks	12.21	15.0	3,655
Rocky Ford, 1927:			
16	13.77	13.9	3,815
32	15.31	15.0	4,577
48	15.92	14.8	4,695
80	15.57	14.8	4,584
Average of checks	15.52	14.8	4,594
Lamar, 1927:			
20	12.06	14.6	3,522
32	12.40	16.6	4,118
48	11.41	15.8	3,607
64	11.32	15.5	3,510
Average of checks	11.68	15.0	3,510
Rocky Ford, 1928:			
20	12.64	16.9	4,231
32	12.96	16.8	4,362
48	12.22	16.6	4,088
64	12.49	15.4	3,842
Average of checks	11.86	16.7	3,968
Lamar, 1928:			
20	14.98	12.5	3,754
32	13.98	12.2	3,385
48	13.16	12.0	3,150
Average of checks	13.31	11.7	3,120

The highest beet yields were obtained from the 60- and 90-pound applications of plant food in the plots located at Rocky Ford in 1925. These plots had a light coating (about 8 tons per acre), of well-rotted cattle manure, and as a result the beets utilized more efficiently the somewhat heavier applications of plant food. At Avondale, in the test which was conducted in 1927 on a fertile field, the beets responded to increased applications of plant food, the 64-pound rate proving to be the best. In 1927 at Rocky Ford, where previous tests indicated the desirability of including some nitrogen in the fertilizer mixture, the 48-pound application of plant food produced the best results, while at Lamar the 32-pound application gave the best results. The experiments conducted at Rocky Ford and Lamar in 1928 showed that the 20-pound application produced beet tonnage yields nearly equal to or better than those obtained with the heavier applications.

The percentage of sucrose in the beet was affected adversely in three out of six tests by the heavier applications of plant food. This occurrence, however, can only be considered as a trend. In sugar yield, plots on which the lighter applications of plant food had been made produced in general the better results.

DISCUSSION

The use of manure in increasing the efficiency of a commercial fertilizer was strikingly shown in a test conducted at Wiley in 1924. Several alternate strips in the field received a 10-ton application of sheep manure. Superphosphate was drilled with the seed at the rate of 60 pounds of plant food per acre. At harvest time, the plots which had received both the superphosphate and the manure produced 3.47 tons more beets and approximately 1,000-pounds more sugar per acre than plots which had received an application of superphosphate alone. These and similar results demonstrate the need of manure or other organic matter in soils commonly planted to sugar beets.

From the results of the work on rates of application it is seen that the rate was reduced from 150 pounds in 1921 to approximately 32 pounds of total plant food per acre in 1928. From this it can be deduced that for most soils of this area which are in an average state of fertility, additions ranging from 25 to 50 pounds of plant food will suffice. On soils rich in organic matter, a reasonable increase in yield of sugar beets may be expected from the application of 60 to 80 pounds. It seems reasonable to expect that as the soils become more mature and the essential elements become depleted either by leaching or by cropping, the rate of application will need to be increased.

SUMMARY

Phosphoric acid is the plant-food element most needed by the sugar beet. Nitrogen in addition to phosphoric acid on the lighter textured soils is also required for the best results. The use of potash in small amounts appears to be beneficial, but not essential in the Arkansas Valley area in Colorado.

Results obtained from tests in which superphosphate and treble superphosphate were compared, indicate that the superphosphate fertilizer is preferable for sugar beets.

Tests conducted with nitrogenous fertilizers indicate the desirability of obtaining some of the nitrogen from organic sources, and the rest from inorganic sources. Where the organic matter in the soil is derived chiefly from residues of alfalfa or other leguminous crops which have been plowed under, additional nitrogen, if required, may be supplied either by sodium nitrate or ammonium sulphate. The results herein reported indicate that sodium nitrate gives more consistent increases in beet yield than does ammonium sulphate. Where the organic matter in the soil is not composed of residues obtained from leguminous crops or of added animal manures, the use of some of the more costly organic nitrogen materials (such as cottonseed meal, tankage, or similar products) in the fertilizer mixture may be justified.

The efficiency of a commercial fertilizer is increased by an abundance of organic matter in the soil. Tests conducted with fertilizer mixtures indicate that larger quantities of the needed plant food can be applied with profit in fields of high fertility than in fields which are in a poor state of fertility. In general, an application varying from 25 to 50 pounds of plant food per acre, of the needed commercial fertilizer, will prove ample for the sugar-beet crop grown on soils of average fertility. For soils that are more fertile, a reasonable increase in yield can be expected from an application of commercial fertilizer, if needed, at the rate of 60 to 80 pounds of plant food per acre. For soils of average fertility an application of 200 pounds of 20-percent superphosphate, or 250 pounds of 16-percent superphosphate, or approximately 100 pounds of treble superphosphate, equivalent to 40 pounds of phosphoric acid per acre, is recommended. A similar rate of 40 pounds of plant food per acre is recommended for mixed fertilizers containing other plant-food ingredients. The experience gained in this valley with applications of commercial fertilizers indicates that applications of these fertilizers at the recommended rates can safely be made with the seed, provided such applications are promptly followed by furrow irrigation.

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